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Shen, Zhongxiang; Shang, Yuping; Xiao, Shaoqiu

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Edge-on Backscattering Enhancement Based on Quasi-Superdirective Reradiation

Yuping Shang, Shaoqiu Xiao, *Member, IEEE*, and Zhongxiang Shen, *Senior Member, IEEE*

Abstract—A concept based on superdirective reradiation is presented for the sake of backscattering enhancement of a thin conducting plate at edge-on incidence. A passive structure consisting of a thin plate loaded with two conducting posts is proposed to demonstrate the concept. Through properly choosing the heights of two posts and the spacing between them, it is observed that the induced surface currents on the two loaded posts are almost 180° out of phase. An obvious enhancement of backscattering can then be obtained as a result of the quasi-superdirective reradiation produced by induced currents on the two loaded posts with each post height shorter than a quarter-wavelength. The induced current distribution is explained by virtue of the image method. Relatively small dimensions of the loaded posts make the design concept appropriate to the backscattering enhancement for airborne applications. The agreement between simulated and measured results validates our design.

Index Terms—Thin plate scattering, backscattering enhancement, superdirective reradiation

I. INTRODUCTION

MANY military and civilian radar targets have component parts that can be called thin plates whose thicknesses are much little in comparison with their lateral dimensions. Although thin conducting plates can generate significant radar returns when their main planes are perpendicular to the illuminating radar line of sight, the backscattering from thin plates at edge-on incidence apparently becomes small, especially when the incident electric field vector is orthogonal to the longitudinal direction of the leading edge [1]. Meanwhile, certain practical applications require the backscattering enhancement, such as the use of small airborne vehicles as tactical decoys for physically large targets, the increase in responses to cooperative radar interrogation [2, 3]. Therefore, the backscattering enhancement technique that is appropriate to the integration with moving targets is of practical interest.

In the past, reported backscattering enhancement techniques or devices include impedance loading, radar reflectors, lenses

and active devices [2, 4]. Recently, the metallic square patches with Sierpinski carpet fractal geometry [5] and a reflectarray made of annular patches [6] were used to enhance the scattering from dihedral corner reflectors. However, the increased drag caused by the large dimensions of these devices is a main disadvantage to them for installation onto moving platforms. Besides, hemispherical [7] and active [8] Luneburg lenses, an electromagnetic scatterer with switch-loaded metallic strips placed above a copper plate [9], a flat reflector based on reflectarray [10] were also reported as scattering enhancement devices. For airborne applications, an open cavity on the wing surface of an unmanned air vehicle was proposed to enhance the scattering [3], while limited information was presented.

On the other hand, as a technique for increasing the antenna gain, superdirectivity has long been an attractive topic in antenna active radiation designs [11, 12]. In order to maximize the antenna gain, proper control of the required excitation magnitude and phase of each radiation element is necessary. However, no previous work has been reported on the scattering from elements with similar source distributions.

In this letter, a concept of quasi-superdirective reradiation is proposed to enhance the backscattering from a thin plate at edge-on incidence. The validity of the concept is demonstrated by a thin conducting plate loaded with two conducting posts. The height of each post is shorter than a quarter-wavelength. It is seen that currents with almost 180° phase difference are induced on the two adjacent posts. The induced current distribution is explained through the dipole counterpart of the presented structure. Compared with the thin plate, the backscattering can be obviously enhanced by the **thin plate** loaded **with** posts. The relatively small dimensions of the posts make the design concept a feasible candidate for integration with moving platforms.

Fig. 1. Perspective view of the proposed structure.

II. CURRENT DISTRIBUTION AND SCATTERING RESULTS

Fig. 1 depicts the thin conducting plate loaded with two

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Y. Shang and S. Xiao are with the School of Physical Electronics, University of Electronic Science and Technology of China, Chengdu 610054, China (e-mail: shangyuping530@sina.com; xiaoshaoqiu@uestc.edu.cn).

Z. Shen is with the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798 (e-mail: ezxshen@ntu.edu.sg).

conducting posts. In this letter copper is used as the conducting material. The lateral dimension of the thin plate is $a = b = 120$ mm (2λ , where λ is the free space wavelength at 5 GHz) and its thickness is $t = 2$ mm. The first post with radius $r_1 = 0.8$ mm and height $h_1 = 12.3$ mm (0.21λ) is attached to the center of the plate, while the second post with radius $r_2 = 1.6$ mm and height $h_2 = 14.2$ mm (0.24λ) is displaced along y-axis with a spacing $y_1 = 8$ mm (0.13λ) with respect to the first post. The propagation direction k of the θ -polarized incident plane wave is from negative y-axis to positive y-axis and the electric field vector $E_0 = 1$ V/m is perpendicular to the longitudinal direction of the leading edge of the flat plate.

According to the image method, the presented structure can be approximately described by two centrally short-circuited dipoles in free space with the plate removed, as shown in Fig. 2. Due to the heights of loaded posts, the length of each dipole is less than a half-wavelength. Since surface current induced on a centrally short-circuited dipole with length less than one wavelength is much similar to a half-sinusoidal distribution, the surface current on the presented dipoles is also a half-sinusoidal distribution. Moreover, by properly choosing dimensions of the two dipoles, especially the length of the first dipole should be slightly shorter than that of the second dipole, it is then found that induced currents on the two dipoles can have almost opposite phases, as shown in Fig. 2 (a). Meanwhile, as seen from Fig. 2 (b), majority currents concentrating around the inner side of this pair of dipoles indicate that the two dipoles are close coupled with each other. Besides the phase difference, a proper coupling is necessary for the backwards enhanced reradiation from this pair of centrally short-circuited dipoles.

Fig. 2. Side view of surface current (a) vector and (b) magnitude distribution on the two dipoles at 5 GHz and 0° phase.

The proposed structure in Fig. 1 can be established through dividing two dipoles in half from the middle by a thin conducting plate, thus currents on the two loaded posts are much similar to that on the upper half of their dipole counterpart. Figs. 3 (a) and (b) show the surface current vector

on the two loaded posts at 5 GHz for different phases. Opposite current directions are also observed on the two closely-spaced posts. The magnitudes of currents obtained by the cross-section integral of surface current density are shown in Fig. 3 (c), where I_1 and I_2 denote the magnitudes of currents along the first post and second post, respectively. The post length in Fig. 3 (c) starts from 0 mm corresponding to the plate-post junction in the xy plane and increases along z-axis to the post end. Although there is a small difference in the amplitudes of induced currents on the two posts, the relative phase difference of induced currents makes the structure much similar to a two-element superdirective monopole array with near end-fire radiation. In such case the quasi-superdirective reradiation produced by the induced current distribution can contribute to the enhancement of backscattering.

Fig. 3. Surface current vector on the two posts at 5 GHz and phase (a) 0° and (b) 180° . (c) Magnitudes of surface currents along the two posts at 5 GHz.

Fig. 4. Magnitude of surface current distribution on the proposed structure at 5 GHz and 0° phase.

The dominant component σ_θ of backscattering is vertical because of the vertically incident E_0 . Since vertical currents contribute to the vertical backscattering component, it is noted

for the proposed structure that the amplitude of vertical currents on the loaded posts is much larger than that on the front and rear edges of the thin plate, as shown in Fig. 4. Thus the dominant scattering source of the proposed structure is vertical currents on the posts, while the dominant scattering source of the thin plate without posts loading is vertical currents on its front and rear edges [1]. Due to different scattering sources, the backscattering characteristic of the thin plate is obviously changed by the proposed structure, as shown in Fig. 5. It is seen that a -22.7 dBsm backscattering peak contributed by the two loaded posts occurs at 5 GHz for the proposed structure. Compared with the thin plate as well as the plate loaded with only the first or second post, the edge-on backscattering is enhanced. In contrast to the plate loaded with only one post, about 8.1 dB enhancement of edge-on backscattering at 5 GHz is obtained by the proposed structure. Relative to the thin plate, at least 10 dB enhancement of edge-on backscattering can be obtained from 3.46 GHz to 5.32 GHz.

In addition, it is noted from Fig. 1 that the angle α between the electric field vector of the edge-on incident plane wave and main plane of the thin plate (xy plane) is 90° . When the electric field vector is tilted so that a certain angle less than 90° but other than 0° is formed, it may be mentioned that the enhancement of σ_θ from the proposed structure relative to the thin plate at 5 GHz can be maintained according to the resolution of electric field vector. On the other hand, the currents on the loaded posts are dominantly vertical, which hardly contributes to σ_ϕ . Therefore, σ_ϕ from the proposed structure is similar to that from the thin plate. Moreover, the enhancement of σ_θ can also occur for other plate configurations, such as circular plates.

Fig. 5. Calculated backscattering from the thin plate, plate loaded with only first or second post, and proposed structure at edge-on incidence.

Figs. 6 (a) and (b) show the backscattering at 5 GHz for different incident angles in yz and xy planes, respectively. The enhancement of at least 10 dB can be maintained within a sector of 26° in yz plane. The backscattering from the proposed structure under incident directions in xy plane is obviously larger than the thin plate due to the loaded posts. The bistatic scattering at 5 GHz from the thin plate and proposed structure at edge-on incidence are compared in Fig. 7. Besides the enhancement of backscattering corresponding to $\phi = 270^\circ$ and θ

$= 90^\circ$, it is seen that an obvious reradiation lobe occurs around the incident direction. Thus the majority of reradiated power by the proposed structure is directed backwards due to induced currents on the loaded posts, which helps retroreflect the incident plane wave.

III. DISCUSSION AND EXPERIMENTAL VERIFICATION

When the lateral dimensions of the thin plate become larger, multiple cells can be attached on the plate with a proper spacing so as to increase the contribution of scattering from the loaded posts. For the sake of an optimum enhancement of backscattering, it may be mentioned that the spacing between neighboring cells may vary according to lateral dimensions of the thin plate involved.

Fig. 6. Calculated backscattering at 5 GHz for different incident angles in (a) yz and (b) xy planes.

Fig. 7. Calculated bistatic scattering at 5 GHz from the (a) thin plate and (b) proposed structure at edge-on incidence.

An example for a thin plate with lateral dimension $a \times b = 600 \text{ mm} \times 120 \text{ mm}$ ($10\lambda \times 2\lambda$) is shown in Fig. 8 (a). Three cells are arranged along x -axis and the spacing between neighboring cells is optimized as $s_x = 60 \text{ mm}$. It is seen that at least 10 dB enhancement of backscattering can be obtained from 3.54 GHz to 5.22 GHz. Fig. 8 (b) shows the backscattering for a thin plate with $a \times b = 120 \text{ mm} \times 600 \text{ mm}$ ($2\lambda \times 10\lambda$). While the plate dimension along y -axis mainly affects the oscillation characteristic of backscattering, two cells are placed along y -axis with a spacing $s_y = 24 \text{ mm}$ and at least 10 dB enhancement are obtained within 3.66 GHz to 5.3 GHz.

In order to verify the simulation observations, the structure presented in Fig. 1 is fabricated and measured. To facilitate measurements, three cells with a spacing $s = 35 \text{ mm}$ are mounted on the thin copper plate with lateral dimension of $120 \text{ mm} \times 120 \text{ mm}$. A photo of this prototype is provided in Fig. 9.

Fig. 8. Backscattering from multiple cells loaded thin plate with increased lateral dimension along (a) x-axis and (b) y-axis.

Comparison of simulated and measured backscattering from the prototype is shown in Fig. 10, where the simulated backscattering from the thin plate with dimension of $120 \text{ mm} \times 120 \text{ mm}$ is also compared with its measured one. The simulated backscattering from the prototype at 5 GHz is -13.6 dBsm, while the measured value is -14.1 dBsm. Although certain frequency shift occurs for the oscillation minima of backscattering from the thin plate, which may be attributed to plate dimension and measurement tolerances, it is noted that the behavior of these curves is generally comparable. The relatively good agreement between the simulated and measured results validates our design.

Fig. 9. Photo of the fabricated prototype.

Fig. 10. Simulated and measured backscattering from a thin plate with lateral dimension of $120 \text{ mm} \times 120 \text{ mm}$ as well as the fabricated prototype at edge-on incidence.

IV. CONCLUSION

It has been shown that surface currents with almost opposite phases can be induced on the two posts attached to a thin plate. The posts with the height shorter than a quarter-wavelength can result in the change of dominant scattering source. The induced current distribution as well as backscattering enhancement has been explained. Dominant scattering sources have been identified. The relatively small dimensions of the loaded posts can facilitate the backscattering enhancement for airborne applications.

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